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Original Article

Habitual sleep patterns and the distribution of body mass index: cross-sectional findings among Swedish men and women

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ABSTRACT

Objective: To compare distributions of body mass index (BMI) between individuals with different habitual sleep patterns.
Methods: We performed cross-sectional analyses of 40,197 Swedish adults (64% women), who reported sleep duration and quality, weight, height, and possible confounding factors in 1997. Using quantile regression, we estimated associations between sleep patterns and selected percentiles of the distribution of BMI.
Results: While the medians were similar, larger adjusted values of BMI were estimated in the upper part of the distribution among men and women with short sleep (≤5 h) compared with medium-length sleep (6–8 h). For example, in men, the 90th percentile of BMI was 0.80 kg/m^2 (95% confidence interval: 0.17–1.43 kg/m^2) higher among short sleepers. In women, long sleepers (≥9 h) also showed larger values in the upper part of the BMI distribution; the 90th percentile was 1.23 kg/m^2 (0.42–2.04 kg/m^2) higher than in medium-length sleepers. In male long sleepers, smaller values were estimated in the lower part of the BMI distribution; the 10th percentile was 0.84 kg/m^2 lower (0.35–1.32 kg/m^2) than in medium-length sleepers. The 90th percentile of BMI in women with poor-quality compared with good-quality sleep was larger by 0.82 kg/m^2 (0.47–1.16 kg/m^2); the 10th percentile was smaller by 0.17 kg/m^2 (0.02–0.32 kg/m^2).
Conclusions: Short, long or poor-quality sleepers showed larger, or smaller, values at the tails of the BMI distribution, but similar medians. Hence, unfavorable sleep patterns and BMI were associated only in a subset of this study population.

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1. Introduction

Between 1980 and 2008, worldwide obesity prevalence nearly doubled from 5% to 10% in men and from 8% to 14% in women [1]. Alongside the obesity epidemic, sleep loss also has become more prevalent, as reflected in the increased percentage of people sleeping ≤6 h [2]. Hence, research into the possible link between sleep loss and obesity is mounting.

Several cross-sectional studies have reported an association between self-reported short sleep duration and higher body mass index (BMI, weight in kilograms divided by height in meters squared) or increased obesity risk [3,4]. Whether sleep duration is related to weight gain, however, is not clear. Prospective studies, from which inferences on the direction of possible causality may be drawn, have yielded mixed results [5]. The literature on sleep quality or sleep disturbances in relation to body weight is less extensive, but studies have demonstrated that worse self-reported sleep quality or sleep disturbances are positively linked to obesity and weight gain [6–8].

Most of the previous studies analyzed the association between sleep and body weight measures using linear or logistic regression models to estimate mean BMI or the probability of obesity, respectively. Associations of sleep patterns with other parts of the BMI distribution have rarely been explored. Quantile regression, which allows for evaluation of predictors across the entire distribution of an outcome variable, such as BMI, has only been used in two studies on the relationship between sleep and body weight in

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adult populations. Both studies indicated that the distribution of BMI differed according to level of habitual sleep duration, so that shorter sleep was associated with higher values of BMI at the upper part of the distribution, particularly in men [9,10]. Better sleep quality was associated with lower values of BMI at the lower part of the BMI distribution in women only [10]. Limited evidence thus suggests that the association with short or poor sleep varies across the distribution of BMI. Similar studies have not been conducted in European populations.

Analyses taking account of the entire distribution of BMI have the potential of providing a more comprehensive picture of the nature of the association between sleep and body weight. They also offer an opportunity to identify subgroups of the population that could be especially susceptible to the putative effects of poor sleep habits. Those subgroups would likely not be identified by approaches analyzing the influence of sleep habits on mean BMI [11]. Furthermore, the vast majority of studies within this research area have focused on sleep duration, typically using one sleep question. There are considerably fewer data on sleep quality and other potentially relevant dimensions of sleep in relation to body weight.

Our aim was to compare the entire distributions of BMI between people with different habitual sleep patterns using quantile regression as analytical approach in a large sample of Swedish men and women. Self-reported sleep assessments were wide-ranging and included sleep duration separately for weekdays and weekends, sleep quality, restorative power of sleep, and daytime sleepiness.

2. Methods

2.1. Study population and setting

We used data from the National March Cohort, established in September 10–14, 1997 as a cohort of volunteers who took part in the National March, a nationwide promotional and fundraising event for the Swedish Cancer Society [12]. Participants in this event, which included a voluntary walk for cancer, were invited to fill out a 36-page questionnaire on lifestyle and medical history. Walking the walk was not a prerequisite for study participation. The Regional Ethics Review Board at the Karolinska Institutet approved the study, and all study participants provided informed consent. The National March took place in 3600 sites throughout the country, and the total number of participants was not assessed. From the 43,880 individuals who completed the questionnaire, we excluded those with inconsistent data ($n = 4$), missing data on age ($n = 13$), age <18 years ($n = 1741$), and missing data on height or weight ($n = 1925$). The final sample included 40,197 participants (14,407 men; 25,790 women).

2.2. Data collection

2.2.1. Body mass index

BMI (kg/m^2) was the outcome variable of interest. Participants self-reported their weight and height in the questionnaire.

2.2.2. Sleep measures

We considered sleep duration on weekdays and weekends, sleep quality, restorative feeling of sleep, and daytime sleepiness as predictor variables. They were assessed using the Karolinska Sleep Questionnaire [13,14], which constituted a part of the study questionnaire. Participants were asked the following: "How many hours do you usually sleep per day on workdays or weekdays?" and "How many hours do you usually sleep per day on off days?" on a six-level scale (<5, 5, 6, 7, 8, or ≥9 h). In our analysis, we categorized sleep duration as ≤5, 6–8 (reference category), and ≥9 h to reflect short, medium-length, and long sleep, respectively. Sleep quality, restorative power of sleep, and daytime sleepiness were assessed using questions on frequency (never, rarely, sometimes, mostly, or always) of relevant symptoms. Sleep quality was a combination of four insomnia-related items: "Have you . . ." (1) "had difficulty falling asleep," (2) "woken up during the night with difficulty going back to sleep," (3) "had restless sleep," and (4) "woken up too early?" Quality was defined as "poor" if participants responded mostly or always to at least one item, "moderate" if they responded sometimes to all items, and otherwise as "good" (reference category). Restorative power of sleep was a combination of three items: "Have you . . ." (1) "had difficulty waking up," (2) "woken up feeling unrested," and (3) "woken up fatigued?" The variable was defined as "poor (nonrestorative)," "moderate," and "good" analogously to sleep quality. Daytime sleepiness could be a consequence of having too short, poor-quality, or poorly restorative sleep. It was assessed with a single item: "Have you been sleepy during the day?" Sleepiness was defined as "yes" if participants responded mostly or always; otherwise as "no". Finally, snoring ("Have you snored heavily?") was defined as "frequent" if participants responded sometimes, mostly or always and "infrequent" if the response was never or rarely. Participants who did not know whether they snored were excluded from analysis.

2.2.3. Other characteristics

Information on age, highest level of education attained (7–9, 10–12, >12 years), level of daily physical exercise (low/moderate/high), smoking status (never/former/current), frequency of alcohol consumption (never, ≤3 times per month, 1–4 times per week, ≥5 times per week), and work schedule (daytime/shift including nights/other/no work) was also obtained from the study questionnaire.

2.3. Data analysis

The distribution of all characteristics by sex and sleep duration on weekdays was examined. Numerical variables were summarized by their median and interquartile range and categorical variables by their frequencies. Quantile regression was used to explore the association of each sleep variable with the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles of BMI. Each 95% confidence interval (CI) was estimated with 500 bootstrap samples. Men and women were analyzed separately because of substantial differences between sexes in the association of sleep duration on weekdays with the considered percentiles of BMI. Age, education, physical exercise, smoking, alcohol consumption, and work schedule were added as covariates. In a secondary analysis, we explored potential effect measure modification on the additive scale between the sleep variables and age or physical activity by visual inspection of stratified distributions. Age and physical activity were strong predictors of BMI, but did not modify the association between the sleep variables and BMI. The relation between sleep duration on weekdays and BMI stratified by sleep quality was also analyzed; individuals with "poor" or "moderate" quality were merged into one category. Finally, the sample was stratified by levels of heavy snoring to examine potential effect measure modification by sleep apnea/snoring, as previously reported [15]. For this analysis, we focused on the upper tail of the BMI distribution, where the potential modifying effect by snoring could be expected to be most pronounced and clinically relevant. We also used multinomial logistic regression to estimate the probability of being in any BMI class (normal range, 18.5–24.99; overweight, 25–29.99; and obese; ≥30 kg/m^2 [16]) given the covariates.

Missing information on the predictor variables affected 5.4% of the initial sample for sleep duration on weekdays; 7.5% for sleep duration on weekends; 0.5% for sleep quality; 0.9% for restorative power of sleep; and 1.1% for daytime sleepiness. For the covariates, the percentage of missing values was <2.0% for education, physical exercise, alcohol consumption, and snoring; 8.0% lacked information on smoking and 8.9% on work schedule. In the

analysis of each sleep variable, participants with missing information were excluded. Depending on the variable, a complete-case data analysis included 78–82% of the initial sample in the adjusted model.

All analyses were performed in Stata, version 12 (StataCorp LP, College Station, TX, USA).

3. Results

3.1. Descriptive characteristics of the study population

Table 1 summarizes the characteristics of the study population according to sex and sleep duration on weekdays. Of the total sample, approximately 8% were short sleepers (≤5 h) and 2% long sleepers (≥9 h). These participants were less educated, less physically active, and more likely to have high-frequency alcohol consumption, nonrestorative sleep, and daytime sleepiness than medium-length sleepers (6–8 h). Obesity was more common in male short sleepers, and in female short and long sleepers. Current smoking, poor sleep quality, and shift work were more prevalent among short sleepers. A higher percentage of short-sleeping men than women extended their sleep on weekends. Women with long sleep reported snoring more often than did those with shorter sleep.

3.2. BMI distribution in men and women by sleep duration on weekdays and sleep quality

After adjustments for age, education, physical exercise, smoking, alcohol consumption, and work schedule, the distributions of estimated BMI values differed between people with short, medium-length, or long sleep durations (Table 2, Fig. 1). Relative to men and women with medium-length sleep on weekdays, larger values were estimated in the upper half of the BMI distribution among those

Table 1
Descriptive characteristics of participants in the National March Cohort by sex and sleep duration on weekdays, Sweden, 1997 ($n = 38{,}035$).

Variable	Sleep duration (h)					
	Men			Women		
	≤5	6–8	≥9	≤5	6–8	≥9
Total	1188 (8.7)	12,177 (89.4)	263 (1.9)	1903 (7.8)	21,923 (89.8)	581 (2.4)
Age (years)	56.2 (41.1–68.2)	54.7 (41.6–65.6)	66.5 (55.9–71.4)	58.5 (47.1–67.5)	49.7 (38.6–59.8)	50.0 (30.9–63.2)
Education (years)						
7–9	478 (41.1)	4355 (36.2)	122 (47.3)	972 (52.2)	7695 (35.7)	227 (40.0)
10–12	477 (41.0)	4525 (37.7)	87 (33.7)	519 (27.9)	6569 (30.5)	194 (34.2)
>12	208 (17.9)	3136 (26.1)	49 (19.0)	370 (19.9)	7275 (33.8)	146 (25.8)
Physical exercise						
Low	369 (31.1)	3048 (25.0)	83 (31.6)	559 (29.4)	5456 (24.9)	178 (30.6)
Moderate	412 (34.7)	4547 (37.3)	94 (35.7)	716 (37.6)	8502 (38.8)	215 (37.0)
High	407 (34.3)	4582 (37.6)	86 (32.7)	628 (33.0)	7965 (36.3)	188 (32.4)
BMI classification[a]						
Normal range	565 (47.9)	6513 (53.8)	138 (52.7)	1064 (57.1)	13,777 (64.1)	317 (56.1)
Overweight	502 (42.6)	4928 (40.7)	112 (42.7)	591 (31.7)	6051 (28.1)	179 (31.7)
Obese	112 (9.5)	675 (5.6)	12 (4.6)	208 (11.2)	1670 (7.8)	69 (12.2)
Smoking status						
Never	609 (58.4)	6835 (61.8)	134 (55.4)	1133 (65.2)	13,344 (64.8)	367 (68.5)
Former	340 (32.6)	3540 (32.0)	95 (39.3)	421 (24.2)	5480 (26.6)	128 (23.9)
Current	94 (9.0)	686 (6.2)	13 (5.4)	183 (10.5)	1770 (8.9)	41 (7.7)
Alcohol consumption						
Never	99 (8.4)	1132 (9.3)	37 (14.1)	291 (15.4)	2566 (11.8)	82 (14.3)
≤3 times/month	424 (36.0)	4459 (36.8)	97 (36.9)	1014 (53.5)	11,823 (54.2)	335 (58.3)
1–4 times/week	558 (47.4)	5796 (47.8)	98 (37.3)	546 (28.8)	7020 (32.2)	143 (24.9)
≥5 times/week	96 (8.2)	736 (6.1)	31 (11.8)	43 (2.3)	426 (2.0)	15 (2.6)
Work schedule						
Daytime	470 (43.9)	6235 (55.3)	58 (26.0)	766 (46.2)	13,645 (66.9)	251 (47.9)
Shift (incl. nights)	188 (17.6)	1418 (12.6)	14 (6.3)	250 (15.1)	2116 (10.4)	42 (8.0)
Other	50 (4.7)	340 (3.0)	4 (1.8)	26 (1.6)	276 (1.4)	4 (0.8)
No work	362 (33.8)	3287 (29.1)	147 (65.9)	617 (37.2)	4372 (21.4)	227 (43.3)
Sleep duration on work-free days (h)						
≤5	553 (48.9)	154 (1.3)	5 (2.0)	940 (53.9)	201 (0.9)	10 (1.8)
6–8	474 (41.9)	9740 (81.6)	20 (8.0)	717 (41.1)	16,042 (75.2)	45 (8.2)
≥9	104 (9.2)	2037 (17.1)	225 (90.0)	86 (4.9)	5096 (23.9)	497 (90.0)
Sleep quality						
Good	627 (52.8)	9767 (80.2)	229 (87.1)	610 (32.1)	16,619 (75.8)	459 (79.0)
Moderate	86 (7.2)	775 (6.4)	8 (3.0)	168 (8.8)	2123 (9.7)	48 (8.3)
Poor	475 (40.0)	1634 (13.4)	26 (9.9)	1124 (59.1)	3173 (14.5)	74 (12.7)
Restorative power of sleep						
Good	800 (67.5)	10,164 (83.5)	215 (81.8)	1201 (63.3)	17,623 (80.5)	443 (76.4)
Moderate	19 (1.6)	146 (1.2)	3 (1.1)	45 (2.4)	454 (2.1)	24 (4.1)
Poor (nonrestorative)	366 (30.9)	1856 (15.3)	45 (17.1)	650 (34.3)	3807 (17.4)	113 (19.5)
Daytime sleepiness						
No	1002 (84.8)	11,405 (93.9)	232 (88.6)	1600 (84.7)	20,394 (93.3)	503 (87.2)
Yes	180 (15.2)	744 (6.1)	30 (11.5)	290 (15.3)	1466 (6.7)	74 (12.8)
Heavy snoring						
Infrequent	528 (44.8)	5890 (48.6)	125 (47.7)	1077 (57.1)	14,122 (64.8)	343 (59.5)
Frequent	514 (43.6)	5189 (42.8)	111 (42.4)	438 (23.2)	4656 (21.4)	147 (25.5)
Undecided	138 (11.7)	1043 (8.6)	26 (9.9)	370 (19.6)	3025 (13.9)	87 (15.1)

BMI, body mass index.
Numerical variables summarized as median (interquartile range), and categorical variables as number (column percentage).
[a] Classes defined as follows: normal range, 18.5–24.99 kg/m^2; overweight, 25–29.99 kg/m^2; obese, ≥30 kg/m^2.

Table 2
Association of sleep duration on weekdays with percentiles of BMI estimated by quantile regression in men and women of the National March Cohort, Sweden, 1997.

Sleep duration	Percentile						
	5th	10th	25th	50th	75th	90th	95th
Men (n = 13,628)[a]							
Model 1							
≤5 h	0.00 (−0.28, 0.28)	−0.10 (−0.38, 0.19)	0.12 (−0.10, 0.35)	0.36 (0.13, 0.58)	0.49 (0.15, 0.82)	1.03 (0.52, 1.53)	2.09 (1.29, 2.89)
6–8 h	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
≥9 h	−0.34 (−0.93, 0.25)	−0.43 (−0.83, −0.04)	−0.20 (−0.59, 0.19)	−0.05 (−0.48, 0.38)	0.32 (−0.27, 0.91)	−0.05 (−1.08, 0.98)	−0.25 (−1.17, 0.68)
Model 2							
≤5 h	0.06 (−0.24, 0.37)	0.06 (−0.18, 0.30)	0.02 (−0.21, 0.25)	0.46 (0.22, 0.71)	0.52 (0.21, 0.83)	0.80 (0.17, 1.43)	1.46 (0.64, 2.28)
6–8 h	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
≥9 h	−0.79 (−1.44, −0.14)	−0.84 (−1.32, −0.35)	−0.39 (−0.96, 0.18)	−0.02 (−0.61, 0.58)	0.19 (−0.23, 0.61)	0.37 (−0.67, 1.40)	0.21 (−0.66, 1.09)
Women (n = 24,407)[a]							
Model 1							
≤5 h	0.11 (−0.16, 0.38)	0.16 (−0.04, 0.37)	0.46 (0.29, 0.63)	0.59 (0.38, 0.81)	0.91 (0.64, 1.18)	1.05 (0.71, 1.39)	1.25 (0.51, 2.00)
6–8 h	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
≥9 h	−0.35 (−0.78, 0.09)	−0.34 (−0.73, 0.05)	0.11 (−0.22, 0.45)	0.51 (0.10, 0.91)	0.87 (0.32, 1.42)	1.62 (0.65, 2.58)	1.62 (0.43, 2.81)
Model 2							
≤5 h	−0.09 (−0.39, 0.21)	−0.08 (−0.37, 0.22)	0.15 (−0.02, 0.32)	0.13 (−0.11, 0.37)	0.51 (0.19, 0.84)	0.90 (0.40, 1.40)	0.83 (0.23, 1.42)
6–8 h	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
≥9 h	−0.33 (−0.95, 0.30)	−0.07 (−0.44, 0.30)	0.24 (−0.19, 0.66)	0.42 (0.04, 0.79)	0.70 (−0.03, 1.43)	1.23 (0.42, 2.04)	1.79 (0.47, 3.10)

BMI, body mass index (kg/m^2).
Data are presented as regression coefficient (95% confidence interval).
Model 1 unadjusted. Model 2 adjusted for age, education, physical exercise, smoking, alcohol consumption, and work schedule.
[a] Number of individuals with complete data on sleep duration on weekdays.

with short sleep. The BMI values representing the 50th, 75th, 90th, and 95th percentiles in men and the 75th, 90th, and 95th percentiles in women were significantly higher by 0.46–1.46 kg/m^2 than the corresponding values in men and women with medium-length sleep. The lower half of the BMI distributions did not differ significantly. Female long sleepers showed a similar shift toward higher BMI values in the upper tail of the distribution (90th and 95th percentiles), consistent with a U-shaped relationship between sleep duration and BMI in this part of the distribution. In men with long sleep, the lower tail (5th and 10th percentiles) was extended toward lower BMI values by 0.79–0.84 kg/m^2; the upper half of the distribution did not differ substantially compared with medium-length sleepers.

Differences were also observed in the distributions of BMI across strata of sleep quality (Table 3, Fig. 2). Women with poor sleep quality showed higher BMI values by 0.30–1.08 kg/m^2 in the upper part of the distribution and lower values by 0.17–0.18 kg/m^2 in the lower tail, compared with good-quality sleepers. A similar pattern, but less marked, was suggested in men.

In men, the adjusted association of short or long sleep duration with BMI did not differ markedly between those with good and poor sleep quality, respectively (data not shown). No striking differences were observed across good- and poor-quality sleepers in women with short sleep either. Compared with medium-length poor-quality sleepers, BMI in women with long sleep, however, appeared to be shifted toward higher values throughout, and particularly in the upper half of the distribution. The 90th percentile was 2.81 kg/m^2 higher in women with long and poor-quality sleep. The corresponding value in women with long and good-quality sleep was 0.66 kg/m^2. Both in men and women, however, the confidence intervals associated with the point estimates of the BMI percentiles were wide, due to this further stratification of the sample.

In the adjusted analysis stratified by snoring, no substantial differences between frequent and infrequent snorers were observed regarding the pattern of association of sleep duration and sleep quality with BMI. In men and women, short sleep was associated with higher BMI values in the upper tail of the distribution among infrequent and frequent snorers, as were long sleep and poor sleep quality among women. The differences relative to medium-length or good-quality sleepers were similar to those observed in the unstratified analysis. As in the analysis stratified by sleep quality, statistical variability was high.

3.3. BMI distribution in men and women by sleep duration on weekends, daytime sleepiness, and restorative power of sleep

The results for sleep duration on weekends, daytime sleepiness, and restorative power of sleep are reported in Supplementary Tables S1–S3. Relative to men with medium-length sleep on weekends, short sleepers showed higher BMI values by 0.37–1.06 kg/

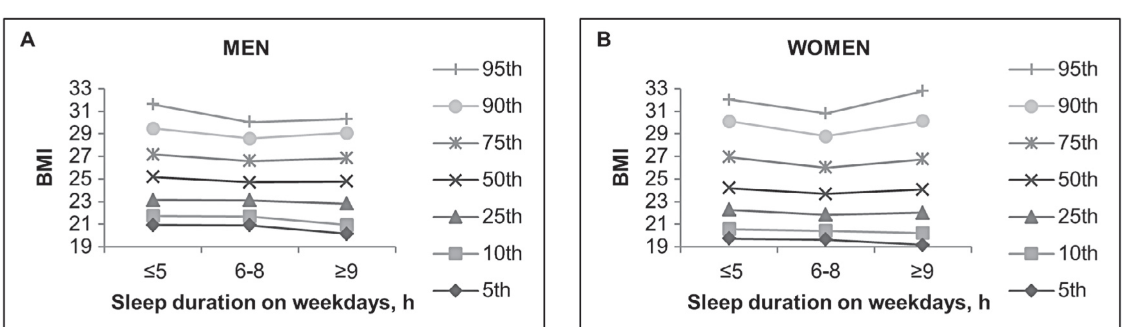

Fig. 1. Average predicted body mass index (BMI, kg/m^2) values at seven percentiles (5th, 10th, 25th, 50th, 75th, 95th), based on adjusted model, by sleep duration on weekdays in men (A) and women (B) of the National March Cohort, Sweden, 1997.

Table 3
Association of sleep quality with percentiles of BMI estimated by quantile regression in men and women of the National March Cohort, Sweden, 1997.

Sleep quality	Percentile						
	5th	10th	25th	50th	75th	90th	95th
Men (n = 14,338)[a]							
Model 1							
Good	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Moderate	0.39 (0.03, 0.75)	0.36 (0.11, 0.60)	0.20 (−0.02, 0.43)	0.21 (−0.00, 0.42)	0.29 (−0.09, 0.66)	0.05 (−0.32, 0.42)	0.23 (−0.66, 1.13)
Poor	0.11 (−0.10, 0.33)	0.11 (−0.06, 0.27)	0.06 (−0.13, 0.24)	0.21 (0.06, 0.35)	0.39 (0.14, 0.65)	0.55 (0.21, 0.89)	0.74 (0.26, 1.22)
Model 2							
Good	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Moderate	−0.14 (−0.50, 0.21)	0.07 (−0.24, 0.39)	0.21 (−0.04, 0.46)	0.11 (−0.15, 0.38)	0.05 (−0.27, 0.36)	0.00 (−0.61, 0.61)	−0.02 (−0.64, 0.59)
Poor	−0.19 (−0.45, 0.08)	−0.04 (−0.25, 0.18)	−0.07 (−0.23, 0.10)	0.11 (−0.09, 0.31)	0.26 (0.02, 0.50)	0.39 (0.06, 0.71)	0.48 (−0.01, 0.98)
Women (n = 25,671)[a]							
Model 1							
Good	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Moderate	−0.02 (−0.26, 0.22)	0.06 (−0.14, 0.26)	0.26 (0.09, 0.44)	0.47 (0.32, 0.62)	0.50 (0.22, 0.78)	0.73 (0.31, 1.16)	0.79 (0.21, 1.37)
Poor	−0.11 (−0.27, 0.05)	0.02 (−0.11, 0.14)	0.26 (0.15, 0.37)	0.42 (0.28, 0.55)	0.78 (0.55, 1.00)	1.08 (0.78, 1.39)	0.95 (0.50, 1.40)
Model 2							
Good	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Moderate	−0.29 (−0.55, −0.03)	−0.12 (−0.32, 0.08)	0.00 (−0.17, 0.18)	0.05 (−0.12, 0.21)	0.06 (−0.20, 0.31)	0.37 (−0.13, 0.86)	0.58 (−0.02, 1.18)
Poor	−0.18 (−0.35, −0.02)	−0.17 (−0.32, −0.02)	−0.06 (−0.20, 0.08)	0.07 (−0.09, 0.24)	0.30 (0.05, 0.55)	0.82 (0.47, 1.16)	1.08 (0.64, 1.52)

BMI, body mass index (kg/m^2).
Data are presented as regression coefficient (95% confidence interval).
Model 1 unadjusted. Model 2 adjusted for age, education, physical exercise, smoking, alcohol consumption, and work schedule.
[a] Number of individuals with complete data on sleep quality.

m^2 in the upper half of the distribution, after adjusting for possible confounding factors. The pattern of association was comparable in women, although the differences between short and medium-length sleepers were smaller than among men and significant for the middle (25th–75th percentiles) rather than the upper part of the BMI distribution (Table S1). The extension toward lower BMI values in the lower tail of the distribution in men with long sleep was not as marked as for long sleep on weekdays (0.27–0.35 vs 0.79–0.84 kg/m^2). There were no significant differences between female long sleepers and medium-length sleepers at any of the estimated BMI percentiles. Relative to men without daytime sleepiness, those who reported being sleepy appeared to have lower BMI by 0.20–0.30 kg/m^2 at the 5th–25th percentiles, although this extension toward lower values was statistically significant for the 10th percentile only (Table S2). Women with daytime sleepiness showed higher BMI values by 0.88–1.10 kg/m^2 at the upper tail of the distribution. There were no meaningful differences in BMI across strata of restorative power of sleep (Table S3).

Men with short sleep on weekends showed higher values in the upper tail of the BMI distribution regardless of snoring status by an order of magnitude similar to the unstratified analysis (data not shown). In women with daytime sleepiness, the extension of the upper tail of the BMI distribution was more evident among frequent snorers than infrequent snorers. For example, relative to women without daytime sleepiness, the 90th percentile of BMI was 0.47 kg/m^2 higher among frequent snorers and 0.07 kg/m^2 higher among infrequent snorers.

3.4. *Relative risk of overweight or obesity by sleep duration on weekdays and sleep quality*

Tables 4 and 5 report crude and adjusted risk ratios of being overweight or obese according to sleep duration on weekdays and sleep quality, respectively, estimated by multinomial logistic regression. Consistent with the results from quantile regression, short sleep was associated with an increased risk of being overweight or obese in men and of being obese in women (Table 4). The adjusted risk of overweight was elevated by 20% in men, and the risk of obesity was increased by 90% in men and 36% in women. Female long sleepers had 29% higher risk of being overweight and 59% higher risk of being obese. We observed no such risk elevations in men with long sleep. Compared with good-quality sleepers, poor sleepers had an increased risk of obesity by 25% in men and 32% in women (Table 5).

4. Discussion

This cross-sectional study is one of the first to examine associations across the entire distribution of BMI within sleep–body

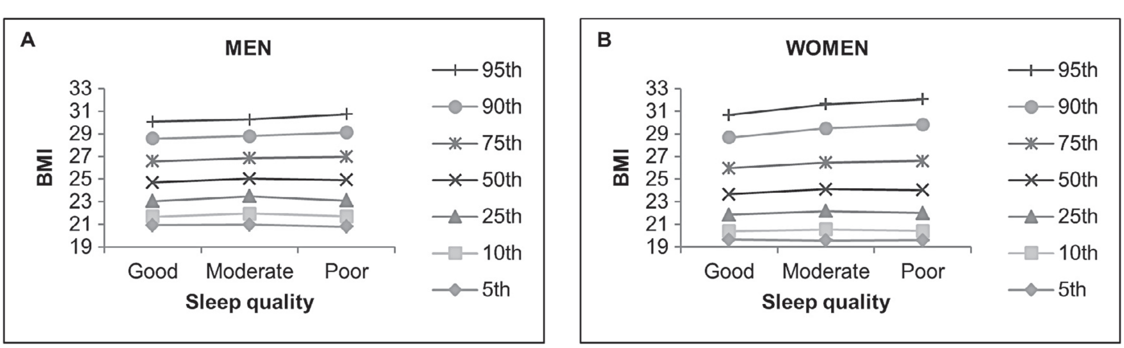

Fig. 2. Average predicted body mass index (BMI, kg/m^2) values at seven percentiles (5th, 10th, 25th, 50th, 75th, 95th), based on adjusted model, by sleep quality in men (A) and women (B) of the National March Cohort, Sweden, 1997.

Table 4
Estimated risk ratios of being overweight or obese associated with sleep duration on weekdays in men and women of the National March Cohort, Sweden, 1997.

Sleep duration	Overweight		Obesity	
	Model 1	Model 2	Model 1	Model 2
Men (n = 13,628)[a]				
≤5 h	1.17 (1.04, 1.33)	1.20 (1.03, 1.39)	1.91 (1.54, 2.38)	1.90 (1.48, 2.45)
6–8 h	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
≥9 h	1.07 (0.83, 1.38)	0.91 (0.67, 1.22)	0.84 (0.46, 1.52)	0.97 (0.52, 1.81)
Women (n = 24,407)[a]				
≤5 h	1.26 (1.14, 1.40)	1.04 (0.92, 1.18)	1.61 (1.38, 1.89)	1.36 (1.13, 1.63)
6–8 h	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
≥9 h	1.29 (1.07, 1.55)	1.29 (1.04, 1.60)	1.80 (1.38, 2.34)	1.59 (1.17, 2.16)

Ref., reference. Values in parentheses are 95% confidence interval.
The base outcome, normal range (body mass index 18.5–24.99 kg/m^2), is omitted from the table.
Model 1 unadjusted. Model 2 adjusted for age, education, physical exercise, smoking status, alcohol consumption, and work schedule.
[a] Number of individuals with complete data on sleep duration on weekdays.

weight research. The distribution of BMI was extended toward higher values in men and women with short sleep duration. Women with long or poor-quality sleep also showed higher BMI values at the upper part of the distribution, whereas men with long sleep displayed lower BMI values at the lower tail. Overall, differences at the middle part of the BMI distributions were smaller than at the tails. The observed associations did not appear to be modified by snoring status, nor did stratification by sleep quality modify the association of short sleep duration with BMI. However, due to the smaller sample size available in the stratified analyses, results on the presence or absence of effect measure modification should be interpreted with caution.

In agreement with the previous literature [15,17–21], this study supports the notion that short habitual sleep duration is cross-sectionally associated with higher BMI values and obesity. Our data further suggest that the distribution of BMI is not parallel-shifted toward higher values in people with short sleep; that is, not all individuals with short sleep show higher values of BMI. Compared with medium-length sleepers, the BMI distribution in short sleepers appeared unaltered in its lower tail and extended in its upper part. This pattern of association could be consistent with increasing BMI values in a limited number of susceptible individuals, whereas a large proportion might be unaffected by short sleep. The reverse is also possible: a small number of individuals could have shorter sleep due to their high body weight. Two previously published studies also showed that the relationship with self-reported sleep was heterogeneous across the distribution of BMI [9,10]. The largest differences across levels of sleep duration were observed at the upper tail of the BMI distribution, primarily among men; longer sleep times were associated with lower BMI values.

Partly consistent with those findings [9,10], women, but not men, with long sleep duration displayed higher BMI values at the upper part of the distribution in our study. Kripke et al. [22] also found a U-shaped relationship between sleep duration and BMI in women only, whereas others [23–25] reported no difference between sexes. Overall, most previously published studies demonstrate a relationship solely between short sleep and increased BMI or obesity risk, and fewer find such associations with long sleep. Some of the inconsistencies across studies are likely explained by differences in age and BMI distributions, analytical approaches, etc. We are unaware of biological mechanisms that would explain the sex-specific association observed at the upper part of the BMI distribution in this study. It is possible that health-related factors or behaviors that we were unable to account for contributed to the observed association in women. However, stratification by snoring status did not alter our results.

Whereas the current study observed no difference between sexes in terms of the association with short sleep on weekdays, the shift toward higher BMI values was more marked in men than in women who reported short sleep on weekends. The positive skewness of the BMI distribution in female long sleepers was also less on weekends than weekdays. The discrepancies in women could be a reflection of the larger contribution of weekday than weekend sleep duration to the total amount of weekly sleep. Indeed, in one study, the relationship with BMI was stronger for sleep duration on weekdays than on weekends [26]. Moreover, a higher proportion of men than women in our study extended their sleep on weekends. A small percentage of men could be especially susceptible to the putative effects of short sleep, or they could be unwilling or, because of their body weight, unable to extend their sleep. This may explain the con-

Table 5
Estimated risk ratios of being overweight or obese associated with sleep quality in men and women of the National March Cohort, Sweden, 1997.

Sleep quality	Overweight		Obesity	
	Model 1	Model 2	Model 1	Model 2
Men (n = 14,338)[a]				
Good	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
Moderate	1.16 (1.01, 1.33)	1.08 (0.92, 1.27)	1.06 (0.79, 1.43)	1.07 (0.77, 1.47)
Poor	1.09 (1.00, 1.20)	1.04 (0.93, 1.16)	1.39 (1.16, 1.66)	1.25 (1.02, 1.54)
Women (n = 25,671)[a]				
Good	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
Moderate	1.21 (1.10, 1.33)	1.02 (0.91, 1.13)	1.39 (1.19, 1.61)	1.20 (1.01, 1.42)
Poor	1.20 (1.12, 1.29)	1.02 (0.94, 1.11)	1.53 (1.37, 1.72)	1.32 (1.16, 1.50)

Ref., reference.
Values in parentheses are 95% confidence interval.
The base outcome, normal range (body mass index 18.5–24.99 kg/m^2), is omitted from the table.
Model 1 unadjusted. Model 2 adjusted for age, education, physical exercise, smoking status, alcohol consumption, and work schedule.
[a] Number of individuals with complete data on sleep quality.

sistency across the week of the association between short sleep and higher BMI values in men. The basis for the association between long sleep and lower values of BMI in men remains unknown.

One previously published study has examined sleep quality in relation to the entire distribution of BMI. Among 6689 American women, Yang et al. [10] found that each unit increase in sleep quality, going from restless to restful sleep on a five-level scale, was associated with lower BMI values at the 30th–40th percentiles of the distribution. The negative difference was greater, but statistically non-significant, at the upper tail of the BMI distribution. No significant differences across levels of sleep quality were observed among men in that study. In a sample of Finns, frequently experiencing insomnia-like symptoms (difficulty falling or staying asleep, etc.) was associated with weight gain of ≥5 kg during a follow-up period of 5–7 years in women only, independently of baseline BMI and other relevant confounders [8]. Similar to our results, non-restorative sleep was unassociated with weight gain in both men and women. Although the definition of sleep quality is variable throughout the literature, our findings are thus in line with previous studies [6–8,10] indicating that worse sleep quality is associated with higher body weight and risk of obesity.

To our knowledge, no study previous has examined sleep duration and sleep quality or disturbance jointly with regard to body weight. In one study, obese men and women with sleep disturbance reported the shortest sleep duration (slightly below 6 h) [27]. Obese or non-obese individuals without such disturbance did not differ in reported sleep durations. These results are not directly comparable with ours, because we used a different analytical approach, i.e. with BMI, not sleep duration, as the outcome variable. Nonetheless, sleep quality did not modify the association between short sleep duration and BMI at the upper part of the distribution, i.e. at BMI values corresponding to obesity. The shift toward higher BMI values in women with long and poor sleep, relative to those with good sleep quality, requires replication in future studies.

We did not confirm the previous finding [15] that snoring, a sign of obstructive sleep apnea, substantially modified the relationships of sleep duration and sleep quality with higher BMI. This dissimilarity could be partly explained by the use of different self-reported measures of snoring; in the case of Lauderdale et al. [15] it can be explained with observed apneas. The shift toward higher BMI values in women with daytime sleepiness in the present study was, however, greater among frequent than among infrequent snorers. Excessive daytime sleepiness is considered the hallmark symptom of sleep apnea, which is also related to reduced sleep times and sleep quality [28]. Had sleep apnea been the explanation for the observed relationships between different measures of habitual sleep and BMI, we would have expected the positive skewness of BMI in individuals with short sleep and poor sleep quality to be stronger among snorers, too. Heavy snoring has been related to daytime sleepiness even in the absence of obstructive sleep apnea [29], and daytime sleepiness is known to be elevated in obese individuals without the said disease [30].

It is beyond the scope of this cross-sectional study to determine the mechanisms by which habitual sleep may influence body weight. However, among suggested pathways are unfavorable alterations in appetite-regulating hormones leptin and ghrelin [31], increased food consumption [32–34], decreased physical activity [35], and positive energy balance [32] resulting from experimentally induced sleep loss. In observational cross-sectional settings, short sleep duration appears consistently and independently associated with increased BMI or obesity [3]. Several prospective investigations have failed to confirm this relationship [15,20,36,37], whereas others have done so [21,38–40]; the direction of the association between inadequate sleep habits and increased body weight remains unclear. The possibility of reverse causation as an explanation for our findings cannot be ruled out.

All the data used in this study were self-reported, as in most large epidemiological investigations. Compared with measured data, self-reported weight is typically underestimated and height overestimated, resulting in lower self-reported BMI. Because underestimation of BMI is greater in overweight or obese individuals than in the normal-weight [41,42], the upper half of the BMI distribution in this study could be biased toward lower values, whereas the lower half would be less affected by misreporting. Any misclassification is, however, likely to be non-differential for sleep habits, leading to greater underestimation of differences across sleep groups at the upper tail of the BMI distribution than at the lower half.

Self-reported sleep duration has been reported to be longer than sleep measured by actigraphy [19,43], although overestimation decreased with longer measured sleep [43]. Obese individuals demonstrated greater accuracy in their sleep duration estimates than did the non-obese, but still overestimated sleep duration [43]. Thus, a smaller proportion of obese true short sleepers than non-obese true short sleepers might have been misclassified as medium-length sleepers in this study, suggesting that misclassification of sleep duration is differential for BMI. This would have resulted in less bias toward the null of the estimated differences between short and medium-length sleepers at the upper tail of the BMI distribution than at other parts. Overall, simultaneous misclassification of sleep habits and BMI probably biased the observed associations downward.

An important strength of this study is the large sample size and assessment of multiple dimensions of habitual sleep. Quantile regression enabled an exhaustive examination of the associations between sleep habits and the entire distribution of BMI, providing a more comprehensive picture of the nature of these associations than typically given.

In conclusion, as limited prior evidence has suggested, we show that differences in BMI according to sleep patterns are heterogeneous across the distribution of BMI. The extension of the tails of the BMI distribution, particularly the upper tail – without a corresponding change of the central tendency – in individuals with short, long or poor-quality sleep indicates that unfavorable sleep patterns and BMI are associated only in a limited subset of people. Although the cross-sectional nature of our data prevents us from drawing conclusions about the direction of causality, our findings are consistent with a small number of individuals being susceptible to the putative effects of unfavorable sleep, whereas a large proportion might be unaffected. Future studies may benefit from using repeated measures over several years and an analytical approach that takes into account the full distribution of BMI to improve the understanding of causal directions and pathways between sleep and body weight in different strata of the population.

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Conflicts of interest

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: http://dx.doi.org/10.1016/j.sleep.2014.06.012.

Appendix: Supplementary material

Supplementary data to this article can be found online at doi:10.1016/j.sleep.2014.06.012.

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